Microvariability

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I Introduction

As measurement techniques continue to improve, many "standard stars" used in photometry, Doppler velocity, and astrometry have been found to be variable. Approximately 10% of the 118,000 stars observed by the Hipparcos mission were found to be variable at levels above 3 millimags (Turon, 1997, Eyer and Grenon, 1997). The following sections sketch some of the most prominent types of variability and discuss the low-level types of variability expected for solar-like stars.

Observations over many years have shown that most types of stars show some variability. See Figure 1. Here only a few of the processes that give rise to variability will be summarized. Then the variability of solar-like stars will be discussed.

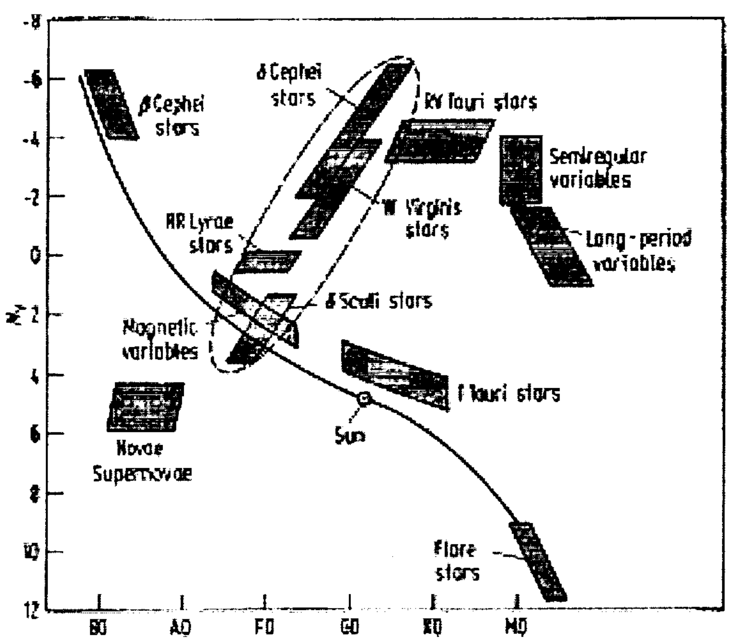

Figure 1. Position of various classes of variables in the Hertzsprung-Russell diagram. The instability strip, which contains most pulsating variables, is bounded by the dashed line. From Herczeg and Drechsel (1994).

<u>Characteristics of Variability</u>

The many different processes that lead to stellar variability cause flux variations over an amplitude range from 10^{-6} for acoustic waves in the stellar atmospheres to 10^{6} for supernova explosions. Time variations of the flux range from seconds to many years. Variations span the wavelength range from X-rays to radio. Consequently, no summary can do justice to the topic of stellar variability. In this paper only a few commonly found types of variability will be summarized.

Generally, the amplitude, period, and structure of variability are related to the luminosity class and spectral type of the star. Supergiant and giant stars (luminosity classes 1, II, and III) of late spectral type (K and M) are often variable with periods exceeding 30 days and have amplitudes greater than 2%. Stars that are of luminosity class III through IV and are of spectral types from A through K have a low probability of being variable. When they do show variability, they usually have low amplitudes and short periods. Other combinations of luminosity class and spectral type have intermediate properties. Grenon (1998) provides comprehensive results for the Hipparcos mission that observed 118,000 stars brighter than 9^{th} mag in the 320 nm to 850 nm spectral band over a period of 3.3 years. Approximately 12,000 of the stars were found to be either variable or suspected of being variable.

Types of stellar variability

Stellar variability is sometimes classified into six categories. The six categories and some examples are:

1) pulsating (RR Lyrae and Cepheid stars)
2) eruptive or cataclysmic (novae and supernovae)
3) rotating (RS Canum Venaticorum, red dwarfs, ellipsoidal variables)
4) eclipsing- and photometric-binary stars (Algols, β Lyrae, W Ursae Majoris, X-ray binaries)
5) flare stars
6) microvariability (defined as amplitude variations less than 1%)

An examination of the light curves is seldom enough to classify the type of variability. Usually, observations of the stellar type and luminosity class are required for classification. Spectral- and radial-velocity measurements also provide needed information on multiplicity, mass ratios, and velocities. The first two types of variability are commonly seen in stars that have evolved off of the main sequence whereas the latter types are usually associated with stars on or near the main sequence.

II. Evolved Stars

Giant stars: These are generally massive stars that have burned their hydrogen, evolved off the main sequence, and have greatly expanded diameters. They have radiation supported atmospheres that often support pulsations and oscillations in size, color, and brightness. Although these stars are rather uncommon, they are intrinsically very bright and can therefore be seen at long distances. Hence a magnitude-limited survey will show a much higher concentration of them near the galactic equator compared to that at higher latitudes. Many types pulsate, often with large amplitudes. Figure 2 shows the brightness variation of eight supergiant stars. These are the classic Cepheid variable stars with periods ranging from a few days to several weeks. The range of amplitudes is quite large and includes some that have very low- and varying-magnitudes like that of Polaris, which has recently become quiescent.

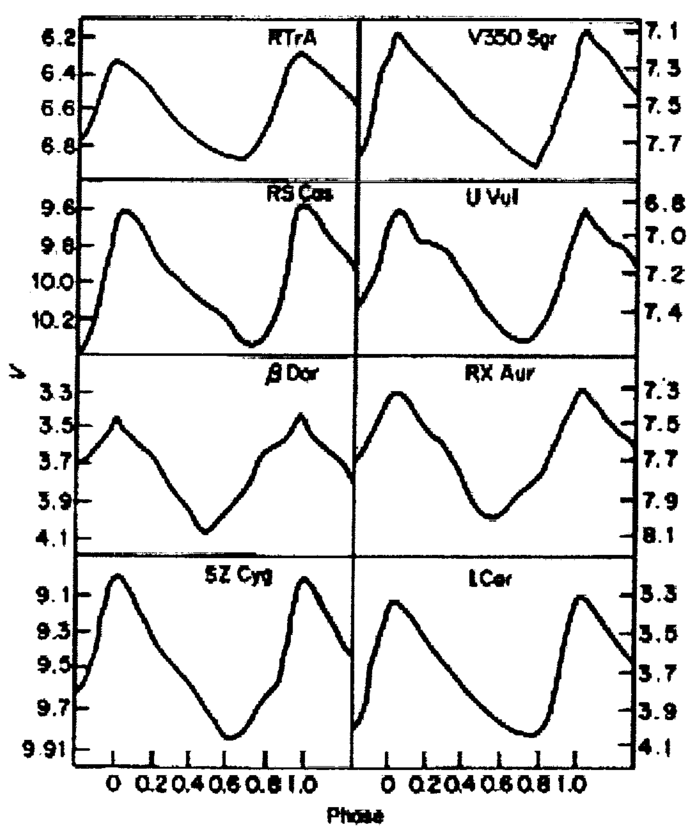

Figure 2. Variability of Eight Cepheid Variable Stars in V magnitudes. The periods range from 3.9 days to 35.5 days. (From Petit, 1982.)

Nova-like activity and Cataclysmic variability

During their quiescent state, these stars show low-level flickering at the 0.001 to 0.1 magnitude levels. On occasion, the star dramatically brightens up as the hydrogen flowing onto the white dwarf from a secondary star ignites a fusion reaction in the hot dense hydrogen that has accumulated on the white dwarf. For other stars, the gas flowing from the Roche lobe of the inflated star flickers as it strikes the star or the orbiting accretion disk. An example is shown in Figure 3. The large dip in brightness in Figure 3b is due to an eclipse of the hot spot.

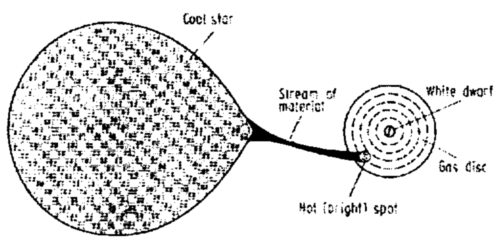

Figure 3a. Schematic diagram of material from a cool star streaming unto an accretion disk around a white dwarf star. From Herczeg and Drechsel (1994).

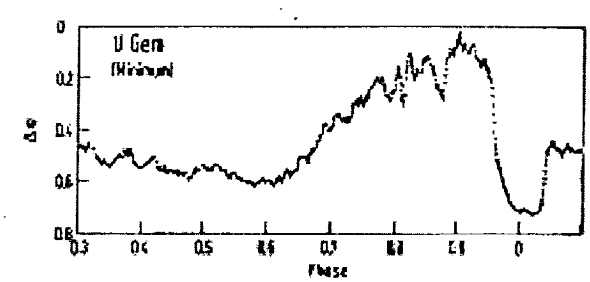

Figure 3b: Light curve for the cataclysmic variable U Geminorum in the minimum state. Eclipse of the hot spot is seen at zero phase. From Warner and Nather 1971 as shown in Herczeg and Drechsel (1994).

III. Main sequence stars

Early spectral classes often rotate rapidly and have radiation-pressure supported atmospheres rather than pressure-supported atmospheres and often show evidence of strong stellar winds. An example is the very rapidly rotating stars of spectral class B. See Figure 4. These stars often show spectroscopic evidence for surrounding rings and envelopes which generate emission and absorption lines. Brightness fluctuations consistent with the ejection of gaseous shells are seen with periods of a few days.

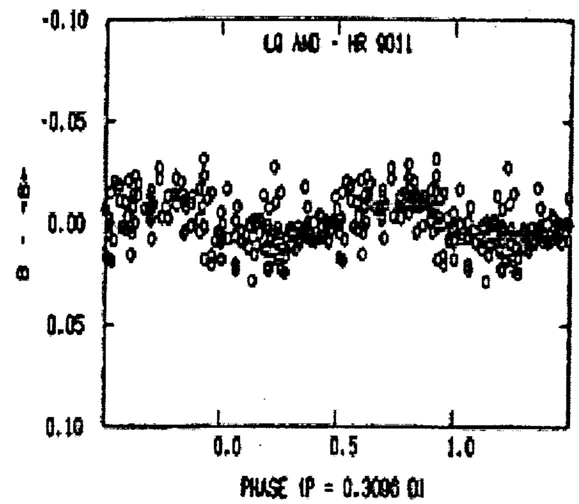

Figure 4. Light curve for Be star LQ And. From C. Stagg. 1983.

Magnetic variables are usually late B- to early F spectral types with strong, variable magnetic fields. Their spectra are variable with respect to occurrence and strength of lines and radial velocities and their brightness shows variations with amplitude of 0.01 to 0.2 magnitudes (Figure 5) as well as variations in polarization.

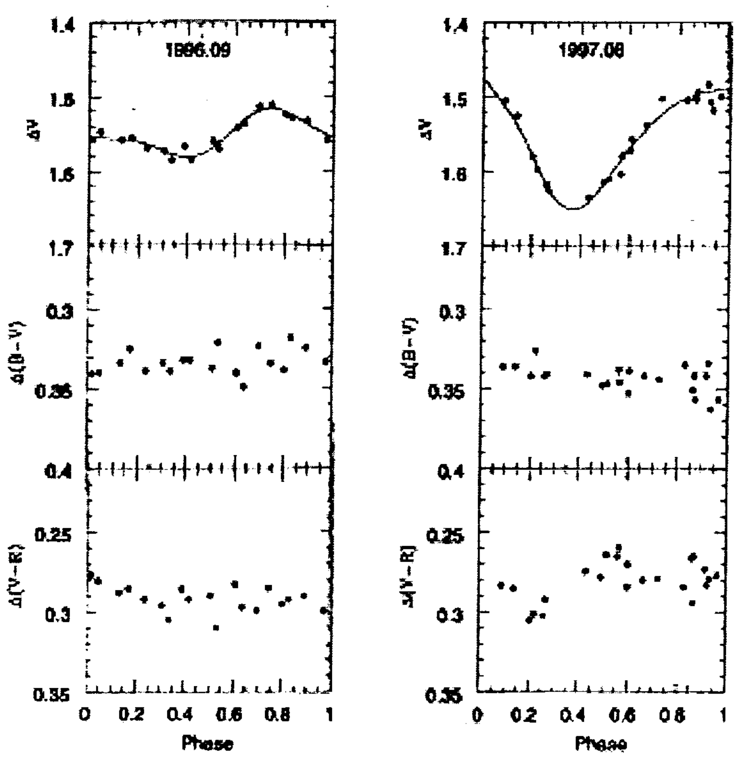

Figure 5. Brightness and Color Variations of Magnetically-active RS Canum Venaticorum Star V711 Tau. From Padmakar and Pandey (1999).

δ Scuti Stars: These stars are non-radially pulsating of spectral types A through F and have luminosity class III through V. Characteristics include periods less than 7hrs and amplitudes often at the 0.01 magnitude level. Note that the photometric-standard star Vega is a δ Scuti star.

Eclipsing stars. About half the "stars" in the sky are actually multiple star systems. Most are binary and about one percent show eclipses because their orbital plane is near our line of sight. Eclipsing binaries show large amplitude variations when both components are approximately the same size, but show very low amplitudes when the secondary is small and when transits are merely grazing. Figures 6 and 7 show a short period interacting binary and a well-separated binary star. In Figure 6, the two stars are so close that their mutual gravity distorts their shapes generating a more complex light curve than seen in Figure 7.

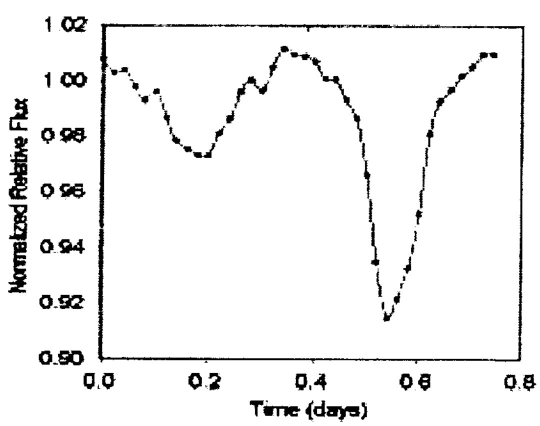

Figure 6. Short period, interacting binary star. (Borucki et al., 2000)

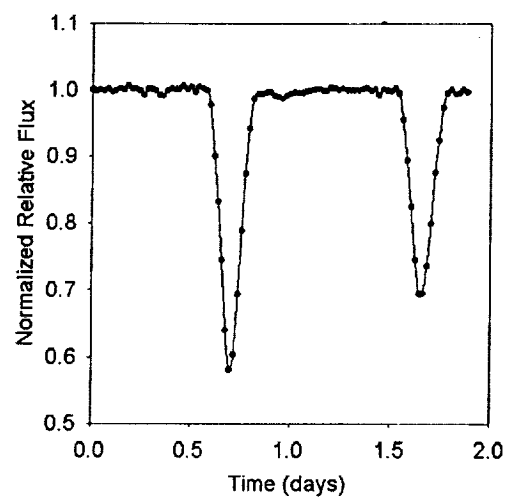

Figure 7. Well-separated eclipsing binary star with 1.9 day period. (Borucki et al, 2000)

Flares:

UV-Ceti-type stars are late type dwarfs (K to M) that show short duration, rapid increases in brightness (flares). See Figure 8. Flares are mostly a chromospheric phenomenon whereas spots are associated with the underlying photosphere. Flares are believed to be due to complex magnetic activity in the chromosphere and corona of the star. On the Sun, the chromospheric activity, as indicated by the H & K lines of CaII, is correlated with the spot cycle. Spot area, plage area, and flare events are correlated with the cycle of magnetic activity. Similar variations of the H&K lines with the flaring activity on K and M dwarfs implies that they too have magnetic activity.

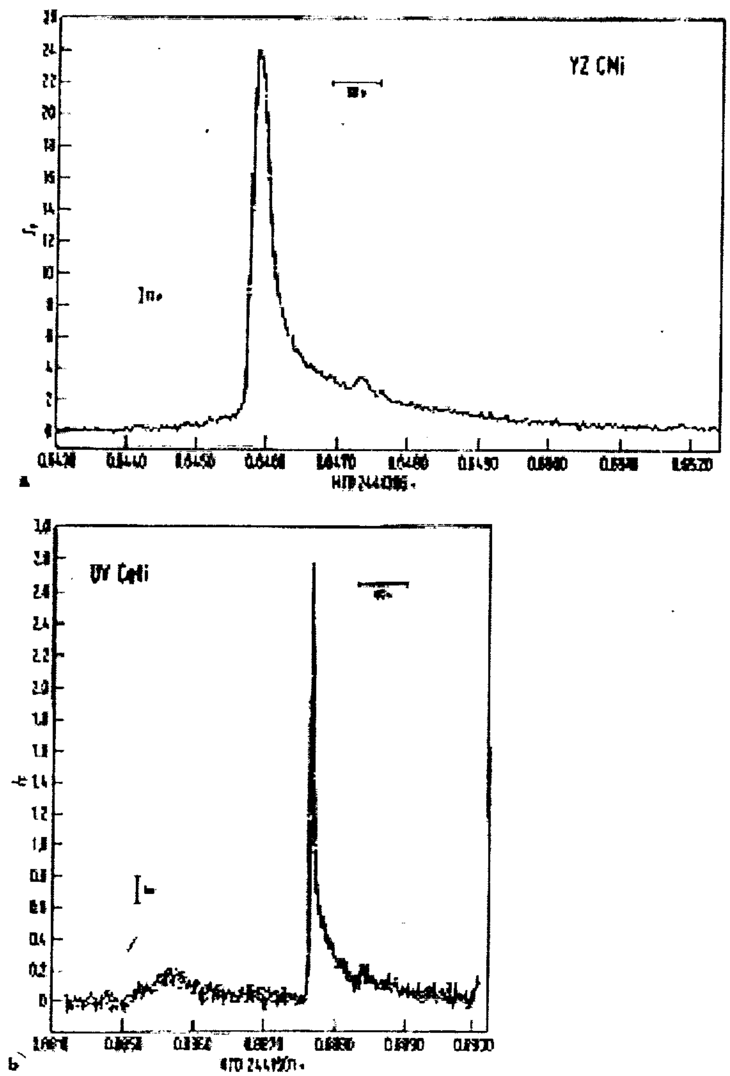

Figure 8. Flux variation from a flare the M-dwarf star YZ Canis Minoris. From Moffat (1974) as presented in Herczeg and Drechsel (1994).

IV. Solar-like Stars

Solar-like stars (G and K dwarfs) are some of the quietest stars known. Nevertheless, they are often spotted and their rotation moves regions of varying spottedness across the visible disk causing noticeable brightness variations. Studies show that spottedness is associated with youth, rotation rate, and atmospheric convection. Young stars (i.e., those less than about $2x10^9$ yrs) often rotate rapidly and have such high levels of spottedness that flux variations of several percent are observed (Radick et al., 1998). Short period binary stars that have synchronized their rotation period with the orbital period show a high level of spottedness regardless of age. Hence it appears that spottedness is directly associated with the rotation rate and only indirectly associated with age. Older stars such as the Sun, rotate slowly and often have activity levels so low that their white-light flux variations can't be detected with the limited photometric precision available from ground-based observations. The simultaneous presence of dim low-temperature spots and bright faculae partially compensate making the Sun less variable than might be expected. In particular, even when the Sun is at the peak of its activity cycle and has large groups of spots present, the visible flux seldom varies by more than 0.1% over a period of weeks. However, observations made in the absorption lines of various metals, such as the Ca II H& K lines, show much higher levels of activity. Because the Ca II line activity is correlated with magnetic activity (i.e., spots and plage), it is possible to estimate white-light activity levels in slowly rotating stars by monitoring the line activity. These observations imply the presence of low level variability in most solar-like stars.

Solar sun spots are cool regions in the photosphere where vertical convection is reduced. See bottom of Figures 9. However, flux variations are much more prominent in the ultraviolet and extreme ultraviolet. See top of Figure 9. A close examination of the photosphere shows that phenomena on several scale lengths can be distinguished. The most readily apparent are the individual convection cells that make up the "granulation" features with scale lengths of about 10^6 m. Figure 10 shows a high resolution visible image of the granulation structure. Larger scale organization into "meso-granulation" and "super-granulation" features also exists. These features have characteristic times for their evolution and dissolution that vary from minutes to a day or more.

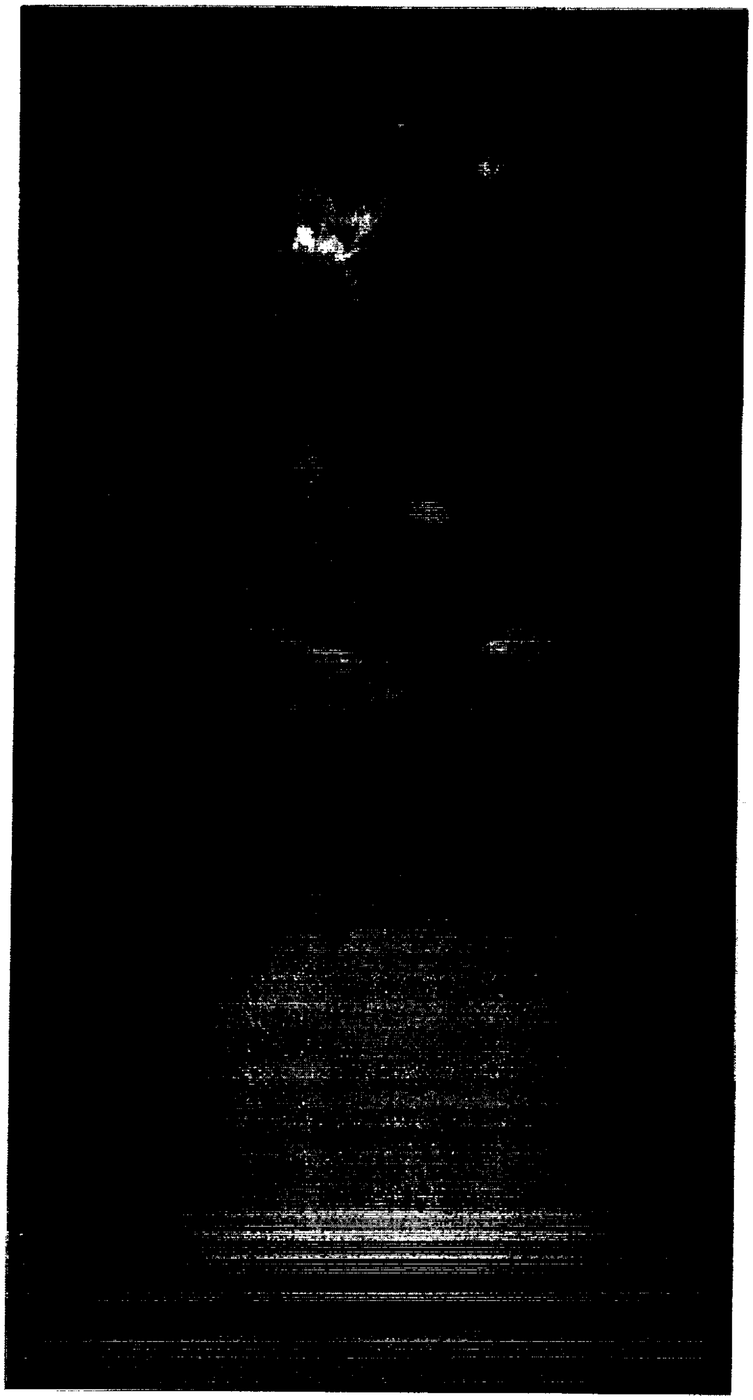

Figure 9. The Sun in the extreme ultraviolet (top) and in the visible (bottom). The sunspots in the lower portion of the figure are in the photosphere whereas the features seen in the top portion of the figure are in the corona.

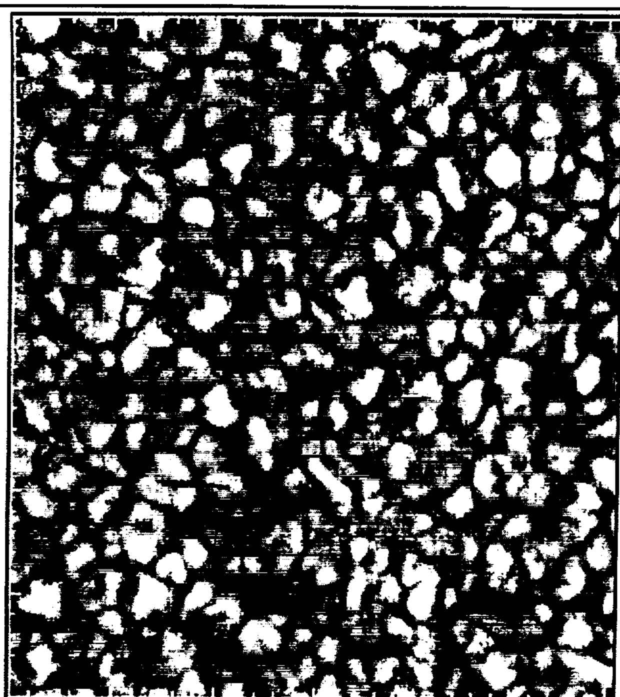

Figure 10. Image of the Sun showing granulation structure. Tick marks show separations of 720 km. From Topeka and Title (1991).

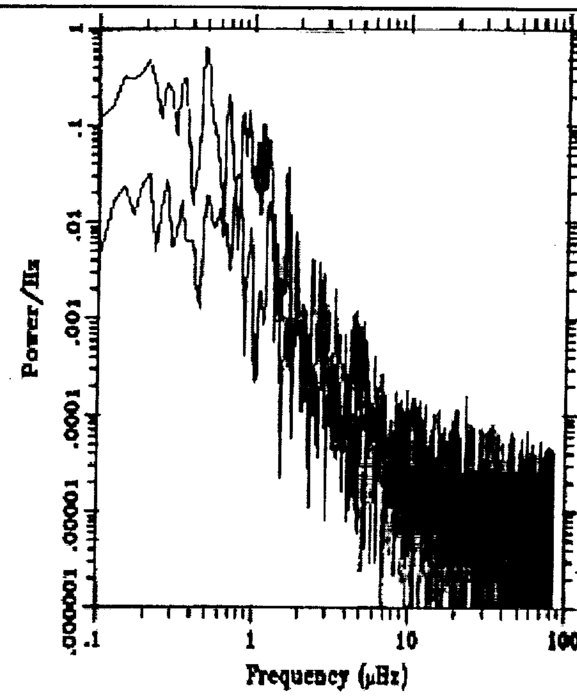

Figure 11. Power spectrum of the Sun at maximum (top curve) and minimum of the solar activity cycle. (1 μHz represents a period of 11.6 days.) From Frohlich et al. 1991.

The power spectrum (Figure11) of solar variability represents amplitudes of these features and their time scales. It shows large amplitudes at periods near the rotation period as various features rotate on and off the disk and shows much lower values at the shorter periods associated with the evolution of these features. Although only features on the Sun have been mentioned, it is likely that most other late-type dwarf stars also have similar features. Hence they too are expected to be variable at all time scales.

The processes that produce noise at periods less than one day (i.e., frequencies > 10 μHz) are uncertain. Possible explanations include variations in the structure of solar granulation, the presence of gravity mode waves, and rotation of plage across the limb. Acoustic waves (p-modes) produce signal amplitudes of a few parts per million at periods near five minutes. These waves and the flux variations that they produce, are also expected to detected on many types of stars when high precision photometry from spacecraft becomes available.

V. Summary

The material presented is only a small sample of the diverse physical processes that cause a wide variety of stars to show variability. As photometric precision improves, more processes will be identified and data from a larger fraction of stars will show evidence of variability. In particular, several space missions (COROT, Kepler, Mons, MOST, SPEX, and Edington) are being developed or proposed that have the ability to detect acoustic waves (p-modes) that have amplitudes near 1 part per million. The Kepler mission is designed to detect the 10^{-4} stellar flux variations caused by transits of Earth-size planets. At some level of photometric precision, it is likely that all stars will show some type of variability.

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